APPENDIX G
Life Sciences

INTRODUCTION

Evidence has been accumulating which indicates that man can survive and perform useful work in space. Consequently it can be assumed that man in space is capable of conducting many of the activities that he accomplishes on Earth. His efficiency and effectiveness, however, are directly dependent upon appropriate training, man-machine interfaces, and supporting technology. If these are inadequate, his proficiency will be lessened.

The roles of man in an Earth-orbital and lunar life sciences program can be divided, at least theoretically, into two categories—passive and active. In his passive role, man is the subject of experimental study, the object of which is to obtain a basic understanding of his ability to function both as an adaptive system and as an integral part of the total space system. In the actual flight situation, the role of man is never purely passive.

In his active role, man is the researcher and experimenter. He possesses a versatile, all-purpose, sensing and responding intelligence capable of processing information, evaluating situations, and making decisions. More specifically, he acts as a sensor, manipulator, controller, and analyst. For example, his presence in space is invaluable, inasmuch as many of the biological processes to be studied there are too complex, subtle, and time dependent for handling and interpretation by fully automated techniques. For certain experiments, highly qualified, on-the-spot judgments would extend experimental capabilities.

A discussion of man's roles in the life-sciences aspect of space flight is the topic of this paper. A section of extracts, "Goals and Research Activities in the Life Sciences" (see p. 121) summarizes specific program objectives and tasks.

PASSIVE ROLE OF MAN

An in-flight study of man is required, because additional medical, physiological, and behavioral data are necessary before prolonged manned missions can be undertaken. This study must include two parts:

1. Medical measurements during prolonged manned space flight and on the lunar surface, to determine—

a. The nature, time-course, and limits of human physiological and psychological adaptation to the space-flight environment.

b. The specific causes and mechanisms by which these adaptations are mediated.

c. The means of predicting the onset and severity of undesirable effects.

d. The means for preventing or ameliorating any undesirable effects.

2. Task-performance measurements to determine the capabilities and limitations of man to perform useful work in space and on the lunar surface, either as a scientist or as an operator. These can be assessed by such measures as task time-line, performance accuracy, and metabolic cost in both nominal and contingency situations. Returned information can be used to optimize man's contribution. Environmental factors believed to affect performance parameters are identified in table G-I.

The knowledge gained from both types of measurements must be of sufficient depth to provide the data upon which future operational and design decisions relating to manned space flight can be based. The effects of weightlessness are the primary unknown here.

The null or subgravity state offers a new dimension of inquiry into human physiology which can be used to supplement ground-based medical research and provide scientific information of value to conventional clinical science and practice.

ACTIVE ROLE OF MAN

In trying to define the potentially active roles of specialists/astronauts, in the life sciences, this study can be divided into five areas of discipline-oriented activity. These are: (1) aerospace medicine, (2) biotechnology, (3) space biology, (4) exobiology, and (5) back-contamination containment and quarantine.

Table G-I.—The Effects of Environmental Factors on Performance Parameters

Performance parameters		Environmental factors	Nominal: Intravehicular: Weightlessness	Relative physical restriction	Altered periodicites	Reduced barometric pressure	Enriched oxygen atmosphere	Presence of diluent gas	Lack of diluent gas	Artificial gravity	Nominal: Extravehicular: Subgravity state	Lack of light dispersion medium	Presence of spacesuit	Need for transient decompression	Off-nominal: Mechanical: Noise	Vibration	Linear acceleration	Rotation	Ambient: Oxygen starvation	Contaminants accumulation	Low or high temperature	Low barometric pressure	Physiological: Inadequate accommodation to 0-g state	Exposure to radiation	Disease	Injury	Human engineering: Inefficient work-rest cycles	Inadequate training	Low-volume per man ratio	Inadequate man/machine interface	Sensory overload or underload	Motivational–emotional: Loss of accustomed patterns	Low interest in work	High cost (e.g., excessive discomfort)	Low reward expectation	Social: Limited social roles	Inappropriate crew structure	Lack of central authority	Lack of privacy	Limited interpersonal interaction
Afferent function	Vision						P					P	P			X	X		X	X	X	X	X															
	Audition														X				X	X	X	X	X																
	Somesthesis												P			X			X	X	X	X	X																
	Smell																																					
	Taste																																					
Efferent function: Function	Orientation	P							P								X			X	X	X	X	X	X	X												
	Positionkeeping	D																																				
	Translation	D							P		P						X																					
	Psychomotor Response								P				P			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Verbal communication							P							X	X	X																					
	Work capacity	D								P		P	D						X	X	X	X	X	X	X	X	X	X											
Efferent function: Quality	Accuracy			P									P		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Speed			P									P	P	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Legend: P = Possible interference or degradation. D = Definite interefence or degradation.
X = Effect whose severity depends on the amplitude of imposed stress.
Where there is no entry, the effect is considered to be comparatively minor or irrelevant.

Possible contributions of man in these areas include:

1. Sensory capabilities, especially in discerning fine detail and slight deviations in patterns.
2. Wide range of manipulative abilities.
3. Highly selective, flexible, and extensive memory.
4. Ability to perceive, interpret, and analyze new situations as they develop in flight. This involves informational discrimination and filtering, establishment and evaluation of alternatives, and real-time decisionmaking.

AEROSPACE MEDICINE

Prior to space flight, untested but plausible theories had been proposed which predicted calamitous failures of various vital functions in an organism suddenly exposed to and maintained in an environment lacking gravitational stimulus. Orbital space-flight experience refuted these theories, and by the end of the Gemini program positive evidence was available to indicate that significant physiological responses were occurring. In considering these flight observations, it is important to realize that the available data are insufficient to permit confident extrapolation to major extensions in mission duration. In addition, the tasks of determining the precise nature, ultimate severity, and fundamental etiology of all changes in man's functional capabilities during and following prolonged space flight are still ahead. Three circumstances, however, make such determination difficult. First, basic knowledge of the "normal" or "reference" functional capabilities of the human organism is relatively limited despite rapid advances in medicine and physiology. For example, individuals of the same build, sex, and age (i.e., matched as well as possible) have different physiological responses to the same treatment. Again, the same individual may respond differently to an identical stress imposed at different times. Second, in-flight stressors act collectively, affect more than one physiological system, and are difficult to evaluate singly. Our present understanding is also inadequate to allow meaningful extrapolations from single to multiple stressors and from one specific composite situation to another. Third, powerful compensatory mechanisms can mask physiological disturbances until conditions become critical.

Although pertinent experiments with varying degrees of human involvement are possible, crew activities are generally reducible to

relatively few tasks. These, for example, include, in order of increasing complexity: (1) equipment manipulation (deployment, adjustment, calibration, etc.), (2) specimen removal and preservation, (3) subjective on-the-spot observations and evaluations, and (4) changes in experiment protocol. In a fully operating space station laboratory, all levels of involvement would be required.

The possibility of illness or injury among astronauts increases with larger crew size, longer flight duration, and more complex missions. Rapid determination of pathological states and on-the-spot effective medical assistance will necessitate the onboard presence of experienced and adequately trained medical personnel.

Finally, it is of scientific interest to explore whether or not the unique qualities of the space environment offer an advantage over conventional medical practice for the treatment of certain pathological conditions occurring on Earth.

BIOTECHNOLOGY

As mission duration and crew size increase, it becomes necessary to recover useful materials from onboard waste to reduce launch weight, volume of stored resources, and resupply requirements. Concurrently, as programs become more ambitious, additional demands are placed on the astronauts, necessitating improvement of living and working conditions. Attention must be given to the design of equipment for more effective man-machine interaction, and to spacecraft architecture for more satisfying habitation. It follows that an in-flight testing and validation program is required to:

1. Determine the adequacy of crew life-support equipment, work and decision aids, and crew protective systems to preserve and enhance astronaut work proficiency and performance effectiveness, both inside and outside the spacecraft.

2. Optimize astronaut habitation in terms of volume utilization, color and decor, clothing, personal hygiene, waste management, thermal/humidity limits, levels of illumination, recreation, social interactions, duty-rest scheduling, and food preparation.

Although approximate mean metabolic rates have been derived from the measurement of carbon dioxide removed by the cabin life-support system, little is known of actual metabolic rates in extravehicular activity, during which rapid breathing and sweating during task performance have consistently occurred. No detailed

evaluations have been made of patterns of muscular activity and motor coordination in the skilled movements of the unrestrained individual in space flight. Although the evidence suggests that brief, heavy overloads can be met adequately, the findings are equally suggestive of impaired capability in prolonged effort, both during and after flight. Rapid heart rates during the physical effort in EVA require careful evaluation of factors in the spacesuit, restraining systems, and working aids design, as well as an assessment of maximum tolerable workloads. From a habitability standpoint, there is a need for careful consideration of the relation between spacecraft architecture and human engineering; i.e., motivational, emotional, and social factors, optimal work-rest cycles, and modes of recreation.

Man's role, in order of increasing complexity, can be envisaged as reducible to: (1) systems operation and research, (2) systems performance evaluation, and (3) systems maintenance and repair.

SPACE BIOLOGY

As our knowledge increases, measurement protocol requirements and experiment operation tasks become so sophisticated that for certain experiments the presence of biologically trained astronauts is necessary. Two distinct goal-oriented classes of activities are envisaged:

1. Experiments using cells and animals to generate the support data required for advanced manned missions. While all data from in-flight experiments with organisms other than man are not applicable to manned flight, they could be of material assistance to this program. Studies in cellular biology will provide unique information on the effects of prolonged exposure to space-flight conditions on basic biological processes. Observation of animals could produce useful information on central nervous, cardiovascular, and metabolic functions. However, to assure the validity of in-flight results, species should be selected that will minimize the problem of extrapolating the animal data to man. In addition, research activities must be planned to supplement medical research in case any problem areas are discovered.

2. Experiments using cells, plants, and animals to increase basic biological knowledge. The unique features of the space environment can be utilized here to analyze basic organism-environment relationships. For example, the attainment of near weightlessness and the

availability of an environment unequivocally disconnected from the Earth's rotation, are environmental factors of obvious biological importance. In both instances, there exist theoretical bases for predicting effects in growth, development, circadian rhythms, and physiological functioning.

Astronaut involvement, in order of increasing complexity, is the same as in the section, "Aerospace Medicine" (p. 114).

EXOBIOLOGY

The search for extraterrestrial life has been recognized as a scientifically valid goal. Three types of relevant activities are possible during Earth-orbital and lunar missions.

1. Multispectral sensing of the planets in search of emission or absorption patterns characteristic of life-associated molecules. Earth sensing will serve as a control for better interpretation of the spectra received from the planets. This activity will also provide valuable information applicable to agriculture, forestry, and possibly marine biology. Although this could be done on an unmanned spacecraft, the presence of man will increase the effectiveness of the data return by assuring proper equipment operation. Additionally, astronauts can aid in the development and refinement of equipment and methodologies that could later be automated.
2. Collect and return lunar samples for bio-organic examination in terrestrial laboratories (early during the lunar exploration phase).
3. Search for and conduct analyses of possible organic materials on the Moon (early during the lunar exploration phase).

BACK-CONTAMINATION CONTAINMENT AND QUARANTINE

To protect the terrestrial biosphere from incoming alien contamination, a capability must be provided outside the terrestrial environment so that returned planetary missions may:

1. Quarantine personnel and equipment
2. Sterilize exposed equipment being returned to Earth.
3. Make preliminary safety analyses of returned planetary samples to assess adaptation and growth under terrestrial condi-

Table G-II.—*Orbital Constraints on Radiation Hazard*

Orbit		Amount and type of use
1) Low altitude Low inclination	200 to 300 nautical miles 0° to 25°	Desirable
2) Low altitude High inclination	200 to 300 nautical miles 50° to 90°	Undesirable
3) Earth-synchronous Low inclination	22 500 nautical miles 0° to 25°	Undesirable
4) Other	.....	.....

NOTE—The preferred orbit is low altitude and low inclination. High-inclination and synchronous orbits are undesirable because of the danger of high radiation flux in the particle fields and exposure to more radiation accompanying solar flare. Additionally, synchronous orbits could interfere with biorhythm studies, because the geophysical periodicities would remain identical to those on Earth. Finally, radiation hazards would make EVA feasible only in low-altitude, low-inclination orbits.

tions, as well as the toxicity and pathogenicity potential before sealing and sending to Earth.

Sterilization of returning planetary probes in Earth orbit does not preclude the possibility of back-contamination, because planetary particles adhering to the probes might be dislodged during orbital capture operations and might drift later to Earth. A base on the Moon, if established for other reasons, could also be used for back-contamination control purposes.

CRITICAL ISSUES

Common to all future manned program alternatives is the necessity for man to function normally in space, tolerate reentry stresses, and readapt successfully to normal Earth conditions.

A decision regarding the necessity of artificial gravity must be made on the basis of whether or not bodily functions are maintained within certain prescribed limits. If artificial gravity is necessary, a further decision must be made concerning the optimal

mode for its provision. It is important, however, to confirm first whether or not the physiological processes observed in both Mercury and Gemini flights are caused by natural acclimatization rather than by gradual and progressive deterioration of bodily functions.

Uncertainties exist regarding both the radiation environment in space and the physiological effect of this environment on man. Evaluation of the radiation hazard in synchronous or high-inclination orbits is limited by the particular model chosen for predicting solar flare activity. Dose-effect relationships are likewise uncertain. Orbital constraints imposed by such considerations are summarized in table G-II.

Engineering constraints limit crew size. Interpersonal-social requirements that must also be satisfied are not easily quantifiable, but do indicate the need for a large crew. Stress can also be caused by limiting both the range of social roles available to the individual and the degree of interpersonal interaction to which each crewmember is exposed.

Experimental data indicate that volume per man is an important factor in reducing behavioral aberrations and that highly habitable environments help in reducing performance decrements and personal stress. However, the relationship between the acceptable minimum volume per man as a function of mission duration (for extended space flight) has yet to be determined, and habitability requirements remain uncertain.

Very little is presently known about the relative duration and type of ground-based simulation necessary to validate a given mission. Extrapolations from simulated to actual events may not have fidelity, if only because crew motivation is expected to vary. Techniques for drawing meaningful inferences from ground-based simulations need to be developed.

The standards for acceptable space-cabin atmospheres should assure maintenance of maximum physiological comfort, physical efficiency, and safety during the flight. These factors include barometric pressure, the nature and abundance of constituent gases, temperature, humidity, and the rate of circulation. Further research to optimize space-cabin atmospheres must continue.

Sources of cabin contamination are of both human and material origin. Atmospheric contaminants that are normally nontoxic may cause adverse physiological effects (ranging from nonspecific functional shifts to incapacitation) under prolonged and continuous

exposure. Therefore, it is necessary to determine tolerance limits, identify means of detection, and establish methods of control to acceptable levels. Operational tolerance limits should be determined through simulations and validated during long-duration flights in Earth orbit. Spacecraft materials must also be studied to identify the extent of toxic and fire hazards they present.

Present life-support systems appear to compromise man's work performance. While this compromise can be tolerated by short-duration missions, it may become increasingly expensive with longer ones. Most tradeoffs between engineering and physiological requirements have been made on the basis of man's very considerable ability to adapt to adverse circumstances, rather than on the basis of clearly defined optimal conditions for effective performance of his role in space. Testing and validation in space of advanced life-support systems is presently considered a pacing item in support of future missions.

CONCLUSIONS

All advanced concepts for the future of manned space flight are structured on either one of two basic assumptions:

1. Man is able to remain in space for long periods of time without physiological aberrations, performance decrements, and permanent injurious effects after returning to Earth; or

2. Physiological or performance degradation can be avoided, through the use of preventive medical measures. These will result from increased space-flight experience and physiological knowledge.

It follows that crew safety, mission success, and optimal use of the astronauts necessitate the establishment of a broad program with two main objectives. The first objective is to understand man's physiological and behavioral response to space flight. The second is to develop the technology required to preserve his physical integrity and enhance his performance capability. The attainment of these two objectives is a prerequisite for achieving all other manned space-flight objectives.

The effort to "space-rate" man will initially demand a large percentage of crew time to conduct experiments in the biomedical and behavioral areas. By about the mid or late 1970's, however, if no major problem areas are revealed, crew time expenditure in these areas could be expected to diminish progressively.

Parts of this section were extracted from the "Space Medicine and Biotechnology" and "Space Biology" program memoranda. Other parts were extracted from working documents generated by the Aerospace Medicine and Biotechnology Subgroup.

Goals and Research Activities in the Life Sciences

SPACE MEDICINE AND BIOTECHNOLOGY PROGRAMS

GOALS

The goals of the space medicine and biotechnology program are: (1) to develop an understanding of man's physiological, psychological, and behavioral reactions as an operator in and of space systems; and (2) to develop a technology for the systems that will provide for man's support and enhance his operational capability. This understanding must be of sufficient depth to provide the data upon which future space-flight program decisions may be based and allow for subsequent design and development of appropriate operational manned space-flight and exploration systems. It must progress at a rate commensurate with the development of the other systems required to achieve the broad goals and specific objectives of the national space program.

OBJECTIVES

The space medicine and biotechnology program is directed to provide critical information with respect to:

1. Man's physiological, psychological, and behavioral reactions to weightlessness and other space stresses for extended periods of time.
2. The requirement for and techniques of providing artificial gravity.
3. Man's capabilities for performing useful tasks in both space vehicles and the extravehicular environment, with and without pressure suits and assistant devices.

4. The environmental requirements and the design criteria for life-support and protective systems, and the technology that will allow and assist man to do useful work in space for extended periods of time.

5. The design criteria for equipment maintenance and reliability and for escape and rescue systems.

The program is divided into three discipline-oriented activities—biomedical and behavioral research (human and animal), man/systems integration, and life-support and protective systems.

Biomedical and Behavioral Research (Human and Animal)

The objectives of this biomedical and behavioral research are:

1. To preserve and extend man's physiological, psychological, and behavioral capabilities during prolonged space flight and on the lunar surface, by determining:
   a. The nature, time-course, and limits of human adaptation to the space-flight environment.
   b. The specific mechanisms through which these adaptations are mediated.
   c. The means of predicting the onset and severity of undesirable effects.
   d. The means for preventing or ameliorating the undesirable effects.
   e. An understanding of the effects of the space-flight environment on human behavior.
2. To utilize the unique qualities of the space environment to obtain scientific information of value to medical science and practice.

Man/Systems Integration

The objective of man/systems integration research is to optimize man's ability to work in space and on the lunar and planetary surfaces by determining, preserving, and extending his performance capability through:

1. The identification of inflight tasks that can best be performed by man.
2. The determination of the optimal measurement techniques required to assess performance.
3. The identification of crew skills and the training needed to insure optimal performance.

4. The development of equipment, design requirements, and techniques for critical operations such as command, control, rescue, transfer, assembly, maintenance, and repair inside and outside the space vehicle.

5. The continued development of methods and design criteria to produce habitable living areas in space and on the lunar surface.

6. The extension of extravehicular performance design information and the continued development of effective work aids.

Life-Support and Protective Systems

The objective of life-support and protective systems technology is to provide a controlled and physiologically acceptable environment for flight crews during all phases of a space mission. The life-support system must, therefore, provide a pressurized shirt-sleeve environment that also allows for pressure-suit operation during normal or emergency conditions. It must supply food, water, and oxygen; provide for personal hygiene; and remove waste and contaminants. Lastly, the system must provide a thermal balance through utilization of available energy and dispersion of any excess heat.

The following parameters necessitate additional life-support system design requirements:

1. As mission duration and crew size increase, it becomes necessary to recover useful materials from onboard wastes to reduce launch weight, volume of stored supplies, and resupply requirements.

2. Prolonged space missions increase the probability of in-flight malfunctions, while more ambitious crew activities impose additional requirements in work performance, especially under suited conditions. Both underline the need for advanced crew protective systems.

RESEARCH ACTIVITIES

For the immediate period ahead, we must attempt to increase our understanding of man's capabilities in and adaptiveness to a weightless space environment for extended periods of time, and pursue those long lead time technological developments of reliably reclaimable life-support and crew protective systems that are essential for long-term, manned space missions.

To accomplish these objectives, research is programed in the three major areas as follows:

1. In biomedical and behavioral research (human and animal)—
   a. Cardiovascular function
   b. Hematology
   c. Respiration
   d. Neurophysiology
   e. Metabolism and nutrition
   f. Microbiology and immunology
   g. Endocrine function
   h. Behavioral effects
   i. Integrated medical and behavioral laboratory measurement system and associated bioinstrumentation
   j. Space pharmacology
   k. Radiobiology
   l. Clinical medicine in space
2. In man/systems integration—
   a. Behavior
   b. Work performance
   c. Habitability
   d. Extravehicular technology
   e. Maintenance and maintainability
   f. Information display and processing
   g. Visual skills
   h. Manipulators and remote controls
   i. Lunar and planetary human factors
3. In life-support and protective systems—
   a. Water management
   b. Waste management
   c. Thermal control
   d. Personal hygiene and sanitation
   e. Atmosphere supply, control, and oxygen regeneration
   f. Carbon dioxide removal
   g. Trace-contaminants control
   h. Astronaut protective systems
   i. Subsystems integration
   j. Closed-spacecraft systems problems
   k. Sensors and instrumentation
   l. Food management

Biomedical Behavioral Research (Human and Animal)

Cardiovascular Function

Statement of the problem.–Space flight has been shown to disturb the homeostasis of the cardiovascular system of man. Decremental changes have been documented in compartmental fluid volumes (plasma volume, red-cell mass, blood volume), hydrostatic pressure (orthostatic hypotension), and related parameters. The extent to which these changes may be exaggerated by prolonged space flights and the extent to which they may adversely affect the performance of man remain to be determined.

Scientific objectives.–To define our understanding of the effects of space environmental factors on the cardiovascular system and determine the effectiveness of preventive and/or remedial techniques. Present assessment indicates that the following need detailed study: (1) central circulation, (2) peripheral circulation, (3) prophylactic and remedial measures, and (4) systems interactions.

Hematology

Statement of the problem.–Detailed hematologic investigations were performed on selected Gemini flights, yielding data from missions of 3 to 14 days in duration. Although a paucity of conclusive data have been obtained thus far, red-cell mass deficits have been consistently observed. More information is needed to determine the cause of this space-flight-related hemolysis. In addition, man's ability to combat infection and repair traumatized tissues under space-flight conditions has not been established.

Scientific objectives.–To describe the qualitative and quantitative changes evoked by space flight in reference to the immunohematologic systems. The significance of hemolysis is of obvious importance to the Manned Space Flight program, for only complete elucidation of its extent, cause, and consequences will permit confidence in committing men to long-duration space missions.

Respiration

Statement of the Problem.—Weightlessness, increased acceleration forces, and artificial atmospheres have major effects on the respiratory gas-exchange function of the body. These effects not only impose health hazards and limitations on man's performance capabilities, but also impose severe design constraints on the spacecraft.

Scientific objectives.—To define the optimal atmosphere for long-duration space missions, establish the mission constraints imposed by this atmosphere, determine any of its adverse effects on man, and determine what mission constraints would be imposed by the choice of a less-than-optimal atmosphere.

Areas that require continued and increased study are:

1. Effects of a gaseous environment
   a. Composition
   b. Dysbarism
   c. Contaminants
   d. Oxygen toxicity
   e. Carbon dioxide
2. Effects of weightlessness
3. Systems analysis

Neurophysiology

Statement of the problem.—To date, the neurological evaluation of space-flight crews has been limited to preflight and postflight clinical medical examinations, the recording of two leads of electroencephalogram of one astronaut for the first 2 days of his flight, and a vestibular experiment that assessed the otolith function of four flight crewmembers during the 8- and 14-day Gemini missions. Although no significant changes were detected, these neurophysiological observations were meager. For extended manned space flight, a thorough investigation of neurological function becomes increasingly important, because this information will have a direct bearing on the determination of what man can do in space and on the development of means to protect his functional integrity during extended flight.

Scientific objectives.—To investigate and evaluate the effects of the space-flight environment and the relative roles of component environmental factors on flightcrew neurophysiological function.

Embodied in this effort are the assessment of the occurrence of adverse effects, the establishment of trend curves, the determination of specific causative factors and mechanisms by which undesired effects become manifest. In addition, the means of prediction and prevention or correction of ill effects must be discovered. To implement these objectives, the following will require special attention: (1) central nervous system function (including sleep, alertness, speech, biorhythms, and emotional reactivity); (2) functioning of the special senses; and (3) peripheral nervous system function.

Metabolism and Nutrition

Statement of the problem.—Some changes related to metabolism and nutrition have been noted in astronauts exposed to 14 days of orbital flight. These changes include reduction in body weight and loss of mineral material in the bones. Such effects may become progressively more serious to the extent of impairing the tolerance of bone structure against torque and shearing, weakening of muscle mass, and possible formation of kidney stones.

Scientific objectives.—To investigate human metabolism and digestion, develop nonsurgical techniques for appraising the human metabolic state, study the control mechanisms that regulate metabolism and energy requirements, and evaluate the effects of the space environment and of drugs on the mobility, digestion, and absorption in the gastrointestinal tract. Detailed study is needed in (1) general metabolism (energy), (2) cellular metabolism, (3) muscle and bone metabolism, and (4) nutrition and gastrointestinal function.

Microbiology and Immunology

Statement of the problem.—The microbiological aspects of manned space flight and the ability of crews to cope with potential infectious agents on extended flights are presently undefined.

The delicate balance between host animal (crew) and its microbial environment in closed and semiclosed ecological systems is precarious, and even minor alterations in diet, physiological or immune state, or the genetic constitution of cohabitant microorganisms may result in the shift of equilibrium to a new balance of

microflora. The dominant species in this new balance may or may not be compatible with the host.

Scientific objectives.—This complex program has as its objective the definition of potential problem areas in long-term host/microflora relationships pertinent to closed or semiclosed ecological systems and the development of optimal methods of control to assure crew resistance to all potentially infectious or pathogenic microorganisms.

The important program study tasks may be reasonably grouped under (1) ecology, (2) host resistance, (3) control measures, and (4) general hygiene.

Endocrine Function

Statement of the problem.—Space flight subjects man to a composite of increased and decreased stresses and, as such, could be expected to affect the endocrine system. Observations from past flights are too sketchy to give a precise picture of how the endocrine system responds to these stresses and, consequently, to those imposed by prolonged space flight. Minimal information gained thus far indicates decreased endocrine activity during flight and increased activity after reentry.

Scientific objectives.—To define the effect of space-flight stresses (both simulated and actual) on the response of the endocrine system. Emphasis should be placed on:

1. Stress indices and tests of endocrine function
2. Methodology (measurement techniques)
3. Endocrine systems: physiological function and mechanisms of each of the systems
4. Remedial and prophylactic measures
5. Systems analysis

Behavioral Effects

Statement of the problem.—The assessment of operational or experimental behavior with objective data under conditions of prolonged stress and confinement, as represented by extended space flight, has not yet been achieved. Returned information will aid in providing baseline data for optimizing the design of the astronaut/spacecraft/crew equipment interfaces.

Scientific objectives.–To (1) assess man's functional ability in completing necessary operational and useful scientific work during long-duration space-flight conditions, (2) assess the spacecraft and equipment design from a human habitability point of view, (3) provide functional ground and in-flight behavioral measurements of sensory-motor performance, and (4) implement experimental and clinical methods for evaluating complex in-flight behavioral changes associated with extended missions.

Integrated Medical and Behavioral Laboratory Measurement System and Associated Bioinstrumentation

Statement of the problem.–Presently available flight biomedical instrumentation consists of little more than vital-sign measurements and as such is inadequate to meet the requirements of mission-rating man for extended flights.

Scientific objectives.–To provide a compact unit in modular form to allow simple exchange of measuring equipment. This will give versatility to the system by enabling the replacement of old with new techniques, and of gross observations with finer measurements and discriminations in the implicated investigative areas. It also allows rapid and less expensive integration of approved in-flight medical experiments and optimization of equipment commonality and crew tasks.

Space Pharmacology

Statement of the problem.–No unfavorable effects to date have been reported in the limited use of drugs during space flights. The use of any drugs on longer missions will require a systematic exploration of the effects of drugs in the space environment and the effects of the space environment on the drugs that may be used. Such a study should include the mode of action, side effects, contamination effects, effects on performance, and drug compatibility. These studies should be carried out in both animals and man under simulated (bedrest) and actual space-flight conditions.

Scientific objectives.–To use pharmacology as a major means of applying protective measures to maintain and restore the mental and physical integrity of man in the space environment. The studies that will be described will be an aid in delineating the physiological effects of the space environment and in designing onboard

diagnostic or prognostic tests. Special attention should be given to: (1) drug metabolism; (2) drug stability; (3) pharmacological manipulation of sleep, behavior, and biorhythms; and (4) dose levels (including determination of chronic toxicity and drug-atmosphere interaction).

Radiobiology

Statement of the problem.– There is significant measurable radiation in the space environment. Exposure of biological materials, including man, to ionizing radiation may produce undesirable effects. The radiation in space is due to particulate radiation such as protons, alpha particles, and electrons. There has been little information available on the biological effects of particular ionizing radiation. The hazards of this type of radiation are presently being determined.

Scientific objectives.–To determine human tolerance levels to space radiation by means of fundamental and applied radiobiology research. The effects of acute and protracted doses of radiation relative to the production of nausea and to injury of critical organs such as the eyes, hematopoietic system, skin, and intestines will be determined in animals and humans, where possible. The following require investigation: (1) molecular and cellular changes, (2) effects on mammalian systems, (3) combined effects of radiation and other stresses, and (4) dosimetry.

Clinical Medicine in Space

Statement of the problem.–The relatively short manned flights to date have posed no medical problems of the sort that would require on-hand clinical diagnostic and/or therapeutic capabilities more elaborate than simple medications and dressings. Extended missions, particularly those that may be physician attended, will require a considerable diagnostic and therapeutic capability that must provide for minor surgical procedures.

Scientific objectives.–To define and develop the diagnostic and therapeutic procedures, medications, and equipment that will be required to maintain the health and well being of the crew. Needed are (1) clinical medicine definition studies, and (2) clinical medicine equipment development.

Man/Systems Integration

There is a need for extensive ground-based research on problems of man/machine integration, habitability, and small-group dynamics. A fruitful medium for studying such effects is in operations that resemble space missions; for example, Antarctic scientific bases and underwater operations such as Sealab and Project Tektite.

These operational simulations, which provide stress and reward conditions that cannot be duplicated in the laboratory, are useful in both: (1) providing many solutions to human engineering problems that occur in space, but are not unique to space, thus enabling in-space research to focus on those problems that are unique to space; and (2) supplying baseline data for comparison with long-term space data, thus clarifying the probable causes of observed in-space effects.

Behavior

Statement of the problem.–From an operational viewpoint, all astronauts to date were capable of carrying out their functions and assigned duties satisfactorily, even under demanding situations in isolated cases (e.g., Gemini 8). However, actual performance was never measured, and it is entirely possible that some degradation actually occurred. Factors that are believed to affect performance include habitability and vehicle design, small-group dynamics, man-systems coupling, physiological status, and motivational or emotional states. For extended manned space flight, the assessment of man's capabilities and limitations in space is warranted. Return information will help optimize the role of the flightcrew and establish the support measures or devices required to preserve and extend human performance in space.

Scientific objectives.–To maximize the effective utilization of man in space, extensive participation by the crew in all activities of the flight program will be required. The astronauts must learn to evaluate the human-factors design features of most onboard systems, report problems and recommend measures to deal with them, and document the evolution of their working methods and other interactions with the machines around them.

1. Small-group dynamics
   a. Crew composition

b. Dominance problems
2. Individual characteristics
   a. Off-duty time
   b. Isolation effects
   c. Social restrictions
3. Mission effects
   a. Stress
   b. Duties

Work Performance

Statement of the problem.—Because it is planned that man will work in the space environment for extended periods of time on longer missions, we must determine what effects the space environment will have on his ability to perform effectively.

Scientific objectives.—It is necessary to investigate human work capabilities in stress environments typical of space. This includes measurement and development of individual performance, psychological adjustment, effective tools and work relationships, and changes in these adjustments and relationships as a function of time and stress. This information will provide crew, job, and equipment design data to minimize individual and crew performance degradation in space. Work performance measures which are meaningful to the astronauts and survey techniques that can be assessed by the crew commander and ground-support personnel are both needed. Ground-based simulation studies must be followed by studies of typical populations under stress in space.

1. Performance measures
   a. Extravehicular activity
   b. Intravehicular activity
2. Work-area physical parameters
   a. Lighting and color environment
   b. Shape and volume
   c. Flexible airlock
   d. Worksite design/packaging
   e. Restraints/work platforms/handholds
   f. Transfer aids/man-translation
   g. Egress/ingress
   h. Tools
   i. Controls and displays

3. Skill proficiency
   a. Dexterity
   b. Reasoning/information processing
   c. Visual/audio; Ames vision test–component
   d. Auditory function
   e. Muscle brain coordination; Ames human transfer function experiment (T-007)
   f. Force generation–fine
   g. Force generation–gross
   h. Assembly tasks
   i. Monitoring and observation
   j. Communication and recording
   k. Physical change
4. Stress effects on work performance
   a. Psychological Adjustment
   b. Interpersonal relationships
   c. Task performance under stress
   d. Work-rest cycles

Habitability

Statement of the problem.–For extended orbital flights, attention must be given to the design of a vehicle and the procedures that will provide for long-term living and work needs.

Scientific objectives.–Individuals and crews will be confined to relatively small habitats in space for extended periods of time. These habitats must be designed to provide optimum comfort, workspace and layout, recreation and relaxation areas, and shape consistent with vehicle size and mission duration.

High-priority efforts that are needed to determine the most habitable design for small crews in long-duration space flight include:

1. Volume, configuration, and layout of crew areas for facilitating work performance and mobility inside the vehicle. This is a function of work tasks, crew size, flight duration, and vehicle size.

2. Basic illumination and special lighting for work, recreation, and sleep activities in various areas in the space station.

3. Effects of modifying interior physical arrangements during the space flight (changeable room sizes and shapes, removable panels, etc.).

4. Basic decor and changes in space stations and in various crew areas during the space flight.

5. Methods for facilitating crew mobility inside the space vehicle; both traffic-flow patterns and handhold and restraints configuration and placement.

6. Methods for achieving individual privacy by physical arrangements or by providing the illusion of privacy.

7. Requirements for simulated day-night cycles for long-duration staytimes (acoustically isolated sleep and rest areas).

8. Various food-management and eating-facility concepts.

9. Protective devices for astronaut safety during free-movement in the space vehicle under zero-g conditions.

10. Off-duty and recreational facilities.

11. Suit don/doff, drying, and storage facilities.

Extravehicular Technology

Statement of the problem.—To achieve the future scientific and technical goals of Earth-orbital manned space flight, it is absolutely essential that man perform useful work. Most of the tasks will be performed from inside the spacecraft, but some may require man's excursion into actual space. Astronauts performing work outside the space vehicle will have to work within the limitations imposed by spacesuits and reduced gravity. They will also have to move themselves and their equipment to the worksite, where they must maintain body position and exert leverage. Maximum safety and minimum EVA time require development of effective mobility systems, design of appropriate worksites, and validation of restraint and anchor devices.

Scientific objectives.—To develop the supporting equipment and techniques for counteracting the difficulties inherent in working in the weightless state under suited conditions. The following extravehicular technology study areas are considered essential:

1. Work-performance capability
   a. Evaluate and develop the capability to control astronaut mobility and attitude in the space-component
   b. Assembly/erection techniques
2. Translation aids (e.g., foot-controlled maneuvering unit)
3. Rescue and retrieval

Maintenance and Maintainability

Statement of the problem.—The probability of a systems failure increases with increasing mission duration. Capability for in-flight maintenance is essential to provide the reliability needed by future space systems. Flight equipment must be designed according to maintainability criteria, and techniques must be established and tools developed to enhance the ability of the astronaut to maintain, repair, and assemble systems in space.

Scientific objectives.—To permit effective repair and/or maintenance of spacecraft systems, base systems, or other equipment crucial to either mission success or crew safety. Study areas requiring attention include:

1. Human performance capabilities and limitations
2. Design of maintainable and repairable systems
   a. Checkout and fault isolation
   b. Accessible packaging
   c. Nonmaintainable versus maintainable tradeoffs
3. Crew assistance systems
   a. Tools
   b. Tethers
   c. Worksite aids

Information Display and Processing

Statement of the problem.—A human information-processing error of any magnitude in space-systems operations could prove disastrous. To insure against this eventuality, we must examine information-processing requirements during actual space-systems operations and develop techniques that will lead to a minimum of error in human information processing.

Scientific objectives.—A satisfactory approach to the problems in this area can be found by developing techniques for displaying all necessary information promptly and unambiguously, and by discovering the principles that govern how information from various sources is effectively combined, how it is retrieved from memory storage and how unnecessary information can be eliminated.

Visual Skills

Statement of the problem.—The environment of space both inside and outside the space vehicle poses unique visual problems.

Man's capabilities and limitations for receiving information through the visual-sense modality in this environment must be determined, and methods developed for optimizing his capabilities in those areas where limitations are discovered.

Scientific objectives.—The specific objectives of visual skills research are to:

1. Develop techniques allowing compression of bandwidth in visual displays.
2. Develop information regarding target characteristics necessary for reliable detection and identification.
3. Develop methods (computer aided) for precise calculation of the probability of target detection and identification.
4. Determine visual capabilities under adverse conditions (e.g., glare in the visual field) and develop techniques for eliminating such adverse conditions when necessary to mission success.
5. Develop visual aids to assist the astronaut.

Manipulators and Remote Controls

Statement of the problem.—In many situations, it will be either unsafe, unfeasible, or impossible for an astronaut to perform his tasks personally. For example, radiation levels might be hazardous, or portable life-support during extravehicular activity might be inadequate, or perhaps the task might be beyond the physical strength of the individual. For these instances, manipulators and remote controls must be developed.

Scientific objectives.—To develop techniques and equipment that can be used in IVA or EVA to supplement man's personal capabilities.

Lunar and Planetary Human Factors

Statement of the problem.—Extensive exploration of the surfaces of the Moon and accessible planets and intensive study of their properties will require parties of men to be present and active for relatively long periods. The human factors involved in such activities will have a few characteristics in common with those encountered in orbital operations, but most of these factors will be new. Lunar surface exploration, for example, will involve extensive activity in a "dusty-vacuum" environment, at an unfamiliar gravity level, and in the presence of hazards very different from those

encountered in extravehicular activity in space. Similarly, life and work in a lunar laboratory, where communications with Earth have low information rates and where there is no quick Earth return capability, will probably differ considerably from human activity in an orbiting laboratory. Extensive study of the human factors involved in such situations is needed if we are to make effective use of men to explore the surfaces of extraterrestrial bodies.

Scientific objectives.—To determine the most effective techniques for manned lunar and planetary exploration. The following areas must be investigated to attain this goal:

1. Shelter and vehicle habitability

a. Define shelter and vehicle requirements for volume, configuration, expendables management, waste and hygiene, food, and radiation and thermal protection.

b. Determine airlock design and dimensional requirements.

c. Establish communications requirements for operations beyond line-of-sight contact.

d. Define configurations and functions for stations that will recharge life-support systems.

e. Determine requirements for stability-augmentation devices for mobility within shelters.

2. Lunar mobility

a. Determine the optimum techniques and devices to aid in walking in 1/6 g.

b. Determine the types of locomotion aids needed for various exploration activities.

c. Devise criteria to assure man-machine compatibility in surface and flying vehicles.

d. Establish communication and navigation requirements.

3. Exploration, maintenance, and repair

a. Define maintenance requirements for habitats and vehicles.

b. Design tools appropriate for use in the 1/6-g environment.

c. Develop procedures and aids for maintenance and repair tasks in 1/6 g.

4. Lunar surface visibility

a. Determine the effects of the lunar (and planetary) visual environment on man's ability to guide himself by visual references.

b. Establish requirements for vision aids needed for manned exploration activities in vehicles or on foot, and for necessary maintenance and repair work.

Life-Support and Protective Systems

Water Management

Statement of the problem.—Current spacecraft life-support requirements, as established by Apollo, do not require water-reclamation systems because of the low weight penalty for storing water for these time periods and because potentially potable water is available from the fuel-cell power system. However, for future mission classes now under consideration, the availability of sufficient water from fuel cells is doubtful, and the weight of stored water is prohibitive. Therefore, water-reclamation systems utilizing the several waste sources available are necessary. These sources are, in order of their ease of purification: humidity condensate, wash water, urine, and feces.

The extent to which these sources of water are utilized will depend greatly on mission class (e.g., oxygen reclamation requires water electrolysis for a closure of the oxygen cycle and, therefore, a greater utilization of waste water for reclamation to balance the water cycle). In all of these mission classes, attention must be given to efficient, reliable systems, using a minimum of expendables, that are capable of providing water for consumption which meets both chemical and biological quality standards.

Scientific objectives.—To advance the technology and develop prototype subsystems to provide for the purification and sterilization of spacecraft waters.

For early missions, only the purification of humidity condensate and urine will be required, with the possible addition of sponge wash water. Chemical purification must be accomplished with minimum power consumption and vehicle interfaces and with a system that has an advanced development status. Sterilization will be required to eliminate bacteriological contamination.

For the intermediate-duration missions, full-body washing water and automatic water flush-fecal collection and processing will also be included. Because the vehicle power source will constrain the desirability of several subsystem concepts for water reclamation and sterilization (i.e., availability of waste heat), multiple subsystem developments will be pursued for both purification functions until a power source is selected. However, even then, because of the different contaminant levels (both chemical and biological), use of a single concept is not likely.

For extended missions, water from fecal matter, food wastes, etc., also will be reclaimed. Both thermal and oxidation techniques will be followed.

1. Water reclamation
   a. Water recovery
   b. Recovery-system pretreatment
2. Potability monitor–potability verification
3. Thermal control–condensing heat transfer and rate

Waste Management

Statement of the problem.–A system for the management of biological waste material must be developed that will meet medical and vehicle integration requirements.

Scientific objectives.–To design and develop an integrated waste-management system that will: (1) provide an inoffensive means of waste collection, mass measurement, and sampling (if required); (2) process biological and other solid waste materials; (3) prevent contamination of the environment with waste material, odors, and micro-organisms; (4) provide for sample preservation and storage; and (5) provide an interface with water-reclamation systems.

1. Collection
   a. Gas transport of solids
   b. Gas transport of liquids
   c. Manual transport of solids
   d. Collector tests
2. Processing
3. Sampling

Thermal Control

Statement of the problem.–Thermal control devices must be developed for maintenance of optimum temperatures during both IVA and EVA. Low-temperature waste heat must be collected and ejected into space, while high-temperature thermal energy must be conserved for use in CO_2/water desorption, water reclamation, etc.

Scientific objectives.–To assure thermal comfort during prolonged space flight.

1. Heat transfer–cooling
   a. Advanced cooling methods

b. Gas to solid heat transfer
2. Heat transfer—heating
   a. Radioisotope thermal heat
   b. Heat-source comparisons
   c. Solid to gas heat transfer
   d. Thermal insulation and surface coatings
   e. Convective heat transfer at zero-g
   f. Material solar absorptivity and thermal emissivity
   g. Nucleate boiling mechanism
   h. Parameters affecting comfort level
3. Atmosphere circulation—cabin air distribution and control
4. Thermal storage systems

Personal Hygiene and Sanitation

Statement of the problem.—Because of the short duration of the Gemini and Apollo missions, personal hygiene and sanitation did not, and were not expected to, pose major health problems. With the advent of extended missions, however, it becomes essential to consider personal hygiene and sanitation as a major problem area from both the medical and crew social requirement aspects.

Scientific objectives.—To develop personal hygiene and sanitation subsystems that will meet crew requirements during extended missions: These subsystems include (1) body-cleansing—evaluation of equipment, (2) whole-body washing, (3) technology for clothing maintenance and cleaning, (4) oral hygiene, and (5) hair removal.

Atmosphere Supply, Control, and Oxygen Regeneration

Statement of the problem.—Oxygen regeneration was not required on short-duration missions (Mercury, Gemini, and Apollo), because the penalty of storing in tanks all the breathing oxygen required was relatively small. As mission durations increase, however, a saving in weight must be effected by breaking down the metabolic carbon dioxide and water given off by man and recovering the oxygen for rebreathing.

Concepts must be evaluated and systems developed to provide oxygen and nitrogen for atmospheric supply, and oxygen for metabolic consumption, with the least weight and volume penalty that is commensurate with the incurrence of reliability loss.

Adequate development status at the time of the mission must also be insured.

Scientific objectives.–To evaluate concepts and develop systems to provide oxygen and nitrogen for atmospheric supply and oxygen for metabolic consumption by (1) developing cryogenic tankage, (2) progressively closing the regenerative cycle and reclaiming oxygen from carbon dioxide and water, and (3) determining a chemically inert, dense source of nitrogen.

For early missions, cryogenic storage systems with their attendant expulsion techniques must be provided. For intermediate-duration missions, storage-system improvements may be required; however, the emphasis must be on development of reclamation systems for obtaining oxygen from metabolic by-products. Existing (or quickly achieved) advanced development status is a requirement. For extended missions, the emphasis should shift to improved recovery efficiency, operational simplicity, and long life in oxygen reclamation. Another source of atmospheric diluent, rather than cryogenic tankage, is also required.

1. Nitrogen and oxygen supply and recovery
   a. Test of storage technology
   b. Oxygen generation from water
   c. Oxygen recovery from CO_2
   d. Airlock gas conservation
   e. Density profile of cryogenic fluid
   f. Capillary studies
   g. Kinetics and dynamics of gas bubbles
   h. Gas-free liquid maintenance
   i. Interface phenomena in liquid gas separation
   h. Supply gaging
2. Trace-Contaminant Control
   a. Absorption of gases by liquids
   b. Humidity control
   c. Water condenser-separator
3. Two-gas control
4. Carbon dioxide control
5. Microbiological control and monitoring

Carbon Dioxide Removal

Statement of the problem.—In any manned-flight situation, the need exists to remove metabolically produced carbon dioxide from the gaseous environment. In longer missions, the requirement exists for concentrating the carbon dioxide for subsequent reduction to minimize or help eliminate the requirement for stored oxygen.

Scientific objectives.—To develop, through extension of the technology now available, subsystems of carbon dioxide removal and concentration with improved reliability and maintenance characteristics. Efforts are also underway to extend adsorption technology and develop water-tolerant adsorption media, while reducing system weight and power requirements. Long-term mission systems are being sought which will have inherently longer life and higher reliability than current adsorption systems. Areas of study are (1) collection methods and components, and (2) atmosphere purification.

Trace-Contaminant Control

Statement of the problem.—Odors and trace contaminants, both physical and biological, must be removed to provide habitable, semiclosed and closed environments.

Scientific objectives.—To provide technology for the control and/or elimination of trace contaminants in spacecraft atmospheres. This includes chemical oxidation techniques, regenerable charcoal sorption of contaminants, and advanced processing techniques.

Astronaut Protective Systems

Statement of the problem.—Present and future manned-space-flight orbital and surface missions require astronaut protective systems that will maintain and support an environmental condition in which useful work may be performed in any operational mode. These systems will protect man from harsh thermal radiation, micrometeoroids, and the vacuum conditions of the extravehicular environment. They also will provide optimum personal environmental conditions within the spacecraft in both normal and emergency situations.

Scientific objectives.—To protect, sustain, and support man against environmental extremes that may occur in orbit or on an

extraterrestrial surface, during all phases of extravehicular and intravehicular manned space-flight missions. This will be accomplished by utilization of spacesuit systems and space life-support systems, which will have high reliability and will be designed for ease of maintenance. Specific weight, volume, power, and overall systems-impact objectives will vary according to the specific class of missions. Research and development in this area will therefore be devoted to (1) intravehicular spacesuit/clothing, (2) extravehicular spacesuit–advanced spacesuit, and (3) portable life-support system–bio-pack evaluation.

Subsystems Integration

Statement of the problem.–Long-term manned missions will require life-support and environmental-control systems of proven performance and with demonstrated reliability, maintainability, vehicle integration, and control automation at the total-system level.

Scientific objectives.–First, to accomplish research and development on individual subsystems to prove the technical feasibility of processes and hardware designs. Subsequently, total systems efforts are needed to identify and solve the problems of scale-up, integration, and control automation. It then is necessary to develop integrated flight-prototype systems that will be used to establish design verification through a long-term ground-test program.

Closed-Spacecraft Systems Problems

Statement of the problem.–In addition to the identified technology problems, there are some systems problems that involve more than one area.

Scientific objectives.–(1) Life support, (2) solid and liquid control, and (3) fire prevention.

Sensors and Instrumentation

Statement of the problem.–For manned spacecraft, a variety of sensors and instruments is required to: (1) measure atmospheric constituents for monitoring and control purposes; (2) detect and identify trace contaminants, including chemical and biological contaminants, to demonstrate the suitability of the atmosphere and

proper operation of the contaminant control system; (3) assess water potability; (4) show proper operation of the entire life-support system; and (5) provide the capability for manual override.

Scientific objectives.—To perform research and development in the area of sensors and instruments to assure that instrumentation will be available to solve adequately the problems that are either currently recognized or anticipated for future space missions—especially intermediate and extended-duration missions. Currently, the sensing and potential control outputs of the atmospheric constituent pO_2 and pH_2 are provided by both polarographic and total-pressure sensors and by a recently developed mass spectrometer two-gas atmosphere sensor. This latter development includes the capability of measuring pCO_2 and pH_2O, in addition to oxygen and nitrogen (or another inert gas).

In the area of contaminant sensing, limited development of flight-qualifiable sensors for early space missions is being undertaken by modification of the two-gas atmosphere sensor and the Apollo gas chromatograph. The development of microwave spectrometers and other types of sensors is essential to: (1) monitor ground simulator atmospheres, (2) evaluate contaminant control systems, (3) establish threshold limit values, (4) perform materials outgassing measurements, and (5) demonstrate candidate flight sensor techniques for intermediate and extended-duration manned missions. Biological sensors for spacecraft atmospheres, and chemical and biological sensors to assure potability of water on manned spacecraft, have not yet received adequate attention. The techniques and associated sensors to accomplish potability assessment of reclaimed water will be developed and tested.

In addition, the development to flight-qualified status of a variety of sensors, such as flowmeters and oxygen and carbon dioxide suit sensors, must be accomplished to verify the proper operation of these systems and provide control functions where necessary.

1. Cabin
   a. Leak defection
   b. Aerosol particle analyzer (T-003)
2. Fire prevention—fire-sensing

Food Management

Statement of the problem.–For future missions food must be tasty, nutritious, simple to prepare, and must store for long periods. Current space foods only partly meet these requirements.

Scientific objectives.–To find ways to prepare and package food for space flight so that it retains its flavor and appeal and serves as a positive morale factor in space missions. In addition, it must be lightweight and small in volume and be easily prepared for consumption in flight.

BIOSCIENCE PROGRAM

BIOSCIENCE GOALS

The goals of bioscience include: (1) the study of the effects of the space environment on living Earth organisms, (2) the use of space flight as a research tool to obtain both new fundamental knowledge and new biomedical applications, and (3) the search for extraterrestrial life.

Space Biology Goals

The goals of space biology are to: (1) study the effects of space environmental factors on living Earth organisms, especially the factors of weightlessness and effective dissociation from factors related to the Earth's rotation; (2) exploit the unique space environment to analyze organism-environment relationships, especially the role of environment in establishing and maintaining normal organization in living systems; and (3) study the physiological, behavioral, and genetic responses and adaptations of living organisms to the space environment.

There is need for a new and better understanding of life processes. The urgency of this need is evident from national and world preoccupation with biological problems, such as food supply, overpopulation, disease, and pollution. The space biology program offers unique and heretofore unavailable opportunities to obtain increased understanding and knowledge that are required in attempting to alleviate these problems.

The most significant characteristics of life are the capacities of living organisms either to maintain a uniform internal environment

in the face of altered external conditions, or to modify the environment to the advantage of the organism and adapt genetically to improve the probability of survival. There is a complicated interrelationship between basic biological functions and environment. The space biology program is now exploiting the use of space as a research tool for new environmental studies. These include studies on the biological effects of weightlessness for prolonged periods, weightlessness combined with radiation, and removal of organisms from geophysical periodicities associated with the Earth's rotation.

Biology's emergence from a descriptive to a quantitative science has been comparatively recent, and it still lacks the establishment of a general theory that is so characteristic of the physical sciences. The ability to conduct studies in unique environmental situations removed from terrestrial influence will significantly aid our approach to such a general theory by increasing our understanding of processes that are universally applicable to all forms of life.

Exobiology Goals

The goals of exobiology are: to obtain knowledge of the origin, nature, levels of development, and distribution of life in the universe, and to develop fundamental theories and models based on this knowledge. These goals require (1) a search for extraterrestrial life and life-related chemicals on the Moon and other planets, (2) study of the early chemical and biological history of the Earth, and (3) prevention of planetary contamination from Earth by effective spacecraft sterilization.

The principal goal in the search for life on another celestial body is to determine the nature of the biota and the state of biological evolution, if life is present, or the presence and nature of organic compounds, if there is no life.

The universality of chemical and physical laws has been demonstrated repeatedly by direct, instrumental observation of various bodies in the universe. No comparable universality of biological laws can be deduced in such a manner, nor can we extrapolate the universality of chemical and physical laws to life as we know it as being the inevitable result of the operation of these laws. Thus, we have unequivocal empirical evidence for biology on only one planet—the Earth. This very fact, however, has caused men

to wonder and speculate not only about possible life on other planets, but also about the very origin of life.

The subject of the possibility of life on other planets has been given the name "exobiology." Indeed, the advent of the space age has even imbued the term exobiology with an attainable goal–that of obtaining data relevant to the origin, nature, and distribution of life in the universe.

To our knowledge, no reasonable concept of life, other than as we know it on Earth, has ever been formulated. Thus, in preparing for the study of exobiology, we are operationally restricted to terrestrial life as a model system. Nevertheless, it is necessary to bear in mind the possibility of life forms that are completely alien to our own planet.

The subject of exobiology is an integral part of any planetary study. The origin, nature, and distribution of life on any given planet is considered to be inextricably interwoven with the origin and evolution of the planet itself and must be studied in that light.

BIOSCIENCE OBJECTIVES

Space Biology Objectives

The main objective is to study the effects of the space environment on living Earth organisms. Carefully selected and controlled experiments are being flown to provide a broad survey of biological effects, preliminary to more detailed studies, to determine the mechanisms of response and adaptation of organisms. Other major objectives are to:

1. Survey the biological effects of weightlessness in Earth orbit on the physiology, morphology, and behavior of various organisms, including primates, rats, invertebrate animals, plants, and single-cell organisms.

2. Survey the effects on the biorhythms of organisms, including rodents, insects, plants, and single-cell organisms, in removing them from Earth's periodicities by Earth- and solar-orbital space flight.

3. Survey the effects of weightlessness combined with controlled radiation in Earth-orbital flight on various organisms.

4. Survey the biological effects of high-energy, heavy-particle, cosmic radiation on selected biological organisms.

5. Initiate studies in space flight on the mechanisms of, and the basis for, response and adaptation of organisms to weightlessness,

space radiation, and removal from Earth periodicities. The achievement of the initial studies will assist the direction of follow-on studies.

Exobiology Objectives

Earth

1. To determine the chemical composition of earliest Earth life, and distinguish between the biological and nonbiological origins of organic matter; to understand the abiogenic synthesis of organic molecules.
2. To determine the extreme parameters of environmental factors that limit biological activity and the influence these factors have on evolution.

Planets

1. To study the physical and chemical characteristics of planetary environments that may be compatible with biological activity.
2. To search for life or life-associated molecules.

Moon

1. To analyze returned samples for biological and/or organic material.
2. To analyze, in situ, life forms or organic material.

Meteorites and Comets

1. To determine the source of the organic matter found in carbonaceous chondrites and its significance with respect to extraterrestrial life.
2. To analyze spectroscopically cometary matter in space, with respect to its organic composition.

Ground-based and extraterrestrial studies required to achieve exobiology goals and objectives can be categorized as: (1) life detection and characterization, (2) chemical evolution and organic geochemistry, (3) environmental parameters affecting life and its

evolution, and (4) development of theories for the origin and evolution of life.

Studies in Life Detection

1. To select those parameters of life that can be determined by remote instrumentation and that will provide data permitting unequivocal interpretation as to the presence or absence of living organisms on the planet being examined. Evidence of metabolic activity, growth, and/or reproduction is considered of primary importance, at least in early missions.
2. To detect and identify organic molecules as evidence for past or present life on a planet.

Studies in Organic Geochemistry

1. To determine the organochemical and/or biochemical history of the Earth.
2. To apply the developed techniques and interpretations to other planets and the Moon.
3. To establish criteria for the differentiation of organic compounds with respect to their biogenic or abiogenic formation.

Studies of chemical evolution have the primary objectives of supplying experimental evidence for the possible origin of life and providing a basis for the recognition of such a process on another planet.

Studies in Environmental Parameters

1. To measure the physical characteristics that constitute the environment for life on the planets.
2. To increase our understanding of the mechanisms by which organisms interact with and adapt to their environment. The environment interacts profoundly with living organisms. When environmental pressure is maintained over a period of many generations, an organism has the opportunity to adapt, through mutation and natural selection in the population. Likewise, the environment may be changed by the biological activity within it. A notable example is the biological production of oxygen in our terrestrial atmosphere.

Theories on the Origin and Evolution of Life

1. To develop general theories based on an understanding of the nature and processes of extraterrestrial life and its distribution in the universe.
2. To describe the line of organochemical-biochemical-biological development within the framework of planetary evolution.

Contamination Control and Biological Constraints

For a manned or unmanned exobiology program in which planetary samples will be acquired; and returned to Earth, consideration must be given to contamination quarantine, the feasibility of sample return, and sample preservation.

Contamination and quarantine constraints.—Control of outbound Earth contamination of the spacecraft is based on the need to protect the validity of life-detection experiments on target planets and on the probability that terrestrial life may grow and spread to change the planetary biota, geochemistry, and atmosphere before scientific exploration is achieved. The probability of growth and spread can be determined experimentally, within reasonable confidence limits, on Earth, after detailed information has become available on the characteristics of the atmosphere, surface, and subsurface environment of the target planet.

Return samples.—Although there is current questioning about the feasibility of returning to Earth even small samples from the surface of Mars, the importance of such samples is sufficiently great to warrant continued study of methods for accomplishing it. Conversely, the potential hazard of contamination of the Earth by extraterrestrial organisms from returned Martian samples is considerably greater than the hazard from samples returned from the Moon, so that the precautions taken should be appropriately greater. It is conceivable that quarantine of returned Martian samples could be conducted on the Moon or in Earth orbit, or that in situ experiments on Mars might resolve the question of hazard.

Sample preservation.—It has been frequently suggested that, to guarantee that extraterrestrial surface material will be preserved from contamination by early spacecraft for future analysis, studies be made to determine a method for preservation, or encapsulation, and to determine the longevity of chemical and biological material under extraterrestrial conditions. Unless complete analyses are

made very early in the program, such preservation should be considered.

MANNED SPACE-FLIGHT PROGRAM

The Advanced Biosatellite should be considered as an alternative to the Biotechnology Laboratory (or comparable manned laboratory), since the manned laboratory is not an economical vehicle for conducting small, automated, nonrecoverable payloads, nor for those experiments requiring short times in orbit. However, if we assume an increase in the overall capacities of space stations and increasing experience in space biology experimentation, there will be a corresponding need for scientist-astronauts.

The experiments planned for a wet workshop will be largely automated, but they will also begin to test man's ability to perform simple laboratory tasks, such as verifying the integrity of living systems in flight, recording physiological variables, and focusing a microscope. Experiments in the intermediate period (1973-1975) will involve more elaborate measurements and manipulative skills. Some of them may also provide for simultaneous automated and astronaut-conducted experiments to allow comparison and evaluation of the effectiveness of the astronaut.

In the post-1974 program, most of the manned space-biology experiments will be carried on in the Biotechnology Laboratory, which may be thought of as a life-sciences laboratory occupying all or part of a manned space station, or perhaps several space stations. It will provide a coordinated space laboratory facility for all of the life-sciences activities of NASA, including bioscience, biotechnology, and space medicine. It is difficult to elaborate on this only in terms of bioscience, because the purpose then will be to achieve maximum common use of skills and equipment for all of the life-sciences work. In general, the trend will be toward greater use of scientist-astronauts trained in the life sciences and toward more general-purpose laboratory facilities. Special experiment packages will be required with some degree of automation as determined by the limited astronaut time, the peculiarities of the experiments, and the nature of the spacecraft environment. It is in this laboratory and during this time period that much of the "intensive" (as distinguished from "survey") experiments will be accomplished. Reusable adaptive equipment is contemplated which will permit repetition and variation of experiments without laborious development and integration work. Observations and procedures performed

by the astronaut will be especially important for simplifying equipment, enhancing the flexibility of the experimental work, and maximizing the scientific output.

BIOSCIENCE PROGRAM PACKAGES

Primates (Bio A)

Scientific objectives.—To extend the study of primate physiology in weightless orbit beyond that accomplished in the biosatellite.

Justification.—

1. To gain a basic knowledge and theoretical understanding of physiological processes in the unique space environment; particularly, to study the mechanisms of response to gravity and Earth periodicities and determine the effects of long-term confinement and the absence of sensory cues on the psychology and physiology of higher order primates. This is a search for fundamental knowledge which will ultimately find use in biomedical research and applications.

2. To learn more about the time course and extent of physiological and psychological changes and adaptation processes in higher order primates subjected to the space-flight environment. This basic research will provide a good empirical comparison with the physiological responses and adaptations observed in astronauts which may be encountered during future space flights. It will provide the analytical basis for evaluating untoward physiological effects that may occur later and for devising appropriate preventive measures.

3. To develop the techniques and technologies necessary to conduct analytical research on large animals in space. This will have particular value in the event that future manned experience indicates a need for more fundamental knowledge.

Component experiments.—(1) The physiology of chimpanzees in orbit, and (2) the hemodynamic and metabolic effects of weightlessness in monkeys.

Microbiology (Bio C)

Scientific objectives.—To extend the survey and in-depth study of the responses of micro-organisms, cells, tissues, and semi-microscopic animals or plants to weightlessness, evolving from results gained in the Biosatellite program toward plans for research in the Biotechnology Laboratory.

Justification.–

1. The biological scientific community has identified a need for these data arising from both survey and in-depth experimentation.

2. The manned space-flight and bioscience communities have endorsed this activity as a means for evolving a flexible, responsive, and powerful mode of carrying out research on the above test subjects in the Biotechnology Laboratory.

3. The capability of long-term space systems to meet the environmental needs and the spacecraft support requirements must be evaluated in the operational environment (e.g., provision of a very low acceleration environment, and isolation of microbiological experiments from rhythmic or cyclic phenomena).

4. The ability of man to monitor, maintain, and repair experiments and equipment must be demonstrated operationally. The capability of the scientist/crewman must also be tested to determine whether he can:

a. Receive microbiological or other culture material.

b. Prepare reusable or adaptable equipment inflight for inflight setup of experiments.

c. Initiate new experiments.

d. Remove, manipulate, and preserve samples.

e. Modify experiment protocol and conditions as required by the price incentive.

f. Terminate experiments, preparing appropriate material for logistics return.

The requirement for, and role of, the microbiology specialist in a space station must be determined in operational tests.

5. Technological requirements must be satisfied for:

a. The evolution of microbiological (and other) research equipment for incorporation in the Biotechnology Laboratory.

b. Providing a low-g research environment free of rhythmic "cue" phenomena.

Component experiments.–

1. Influence of zero gravity on isolated human cells (further development of S015).

2. Behavior and reproduction of paramecia in the weightless state.

3. Effect of zero gravity on the growth rate of yeast and *E. coli.*

4. Growth of a plant tissue culture in the gravity-free state.

5. Effect of the space environment and weightlessness on

periodicity of growth and conidial formation in *Neurospora* "clock-mutants."

6. Effect of subgravity on frog egg development.

7. Automatic analysis of cytogenic material.

8. Kinetics of DNA replication and recombination under weightless conditions.

Small Vertebrates (Bio D)

Scientific objectives.—To extend the survey and in-depth study of the responses of small vertebrate animals to weightlessness, evolving from results gained in the Biosatellite program toward plans for research in the Biotechnology Laboratory.

Justification.—

1. The biological scientific community has identified a need for these data arising from both survey and in-depth experimentation.

2. The manned space-flight and bioscience communities have endorsed this activity as a means for evolving a flexible, responsive, and powerful mode of carrying out research on the above test subjects in the Biotechnology Laboratory.

3. The capability of long-term space systems to meet the environmental needs and the spacecraft support requirements must be evaluated in the operational environment (e.g., provision of a very low acceleration environment, and isolation of vertebrate animal experiments from rhythmic or cyclic phenomena).

4. The ability of man to monitor, maintain, and repair experiments and equipment must be demonstrated operationally. The capability of the scientist/crewman must also be tested to determine whether he can:

a. Receive test animals.

b. Perform in-flight experimental preparation of animals for installation in onboard experiment modules.

c. Make direct observations of recordings on the test subjects.

d. Perform various specimen collection and preservation techniques, including biopsy, body-fluid sampling, sacrifice, and necropsy.

e. Make serendipitous or *ad hoc* demand observations.

f. Modify experiment protocol and conditions.

g. Terminate animal experiments, preparing both life specimens and preserved material for logistics return.

The requirement for, and role of, an animal physiology specialist in a space station must be determined in operational tests.

5. Technological requirements must be satisfied for:

a. The evolution of small-animal research equipment for incorporation in the Biotechnology Laboratory.

b. Providing a low-g research environment free of rhythmic "cue" phenomena.

Component experiments.—The experiments comprising Bio D are grouped in eight areas, characterized either by (1) potential for common use of the same test individuals by a number of principal investigators, (2) the unique importance of the biological area of interest, or (3) the unique environmental conditions required by the test subjects.

1. The role of gravity in cardiovascular function (one experiment).

2. The role of gravity in embryogenesis, parturition, growth, development, metabolism; and again in rodents (11 experiments).

3. The role of gravity in immune responses of mammals (two experiments).

4. The role of gravity in embryogenesis and development in amphibia (one experiment).

5. The role of gravity in growth and metabolism in reptiles (one experiment).

6. The influence of gravity on behavior in mammals (one experiment).

7. The influence of geophysical factors on biorhythms in vertebrates (two experiments).

8. The role of gravity in hibernation (one experiment).

Plant Specimens (Bio E)

Scientific objectives.—To extend the survey and in-depth study of the responses of a variety of plant species, evolving from results gained in the Biosatellite program toward plans for research in the Biotechnology Laboratory.

Justification.—

1. The biological scientific community has identified a need for these data arising from both survey and in-depth experimentation.

2. The manned space-flight and bioscience communities have endorsed this activity as a means for evolving a flexible, responsive, and powerful mode of carrying out research on the above test subjects in the Biotechnology Laboratory.

3. The capability of long-term space systems to meet the environmental needs and the spacecraft support requirements must be evaluated in the operational environment (e.g., provision of a very low acceleration environment, and isolation of plant experiments from rhythmic or cyclic phenomena).

4. The ability of man to monitor, maintain, and repair experiments and equipment must be demonstrated operationally. The capability of the scientist/crewman must also be tested to determine whether he can:

a. Receive plant seeds, tissues, or other material.

b. Perform in-flight experimental preparation of plant materials for installation in onboard experiment modules.

c. Make direct observations of recordings on the test material.

d. Perform various specimen collection and preservation techniques, including macro-dissection for particular organs or tissues.

e. Make serendipitous or *ad hoc* demand observations.

f. Modify experiment protocol and conditions.

g. Terminate plant experiments, preparing both live specimens and preserved material for logistics return.

The requirement for, and role of, a plant physiology/morphology specialist in a space station must be determined in operational tests.

5. Technological requirements must be satisfied for:

a. The evolution of plant research equipment for incorporation in the Biotechnology Laboratory.

b. Providing a low-g research environment free of rhythmic "cue" phenomena.

Component experiments.—

1. Plant responses from 0 to 1 g.

2. The role of Auxin mediated reactions in the developing wheat seedling during weightlessness.

3. Pea seedling growth in orbit.

4. The effect of weightlessness on gametogenesis and morphogenesis of Pteris gametophytes.

5. Studies of the circadian leaf movements of pinto beans.

6. Environmental factors regulating circadian rhythms in *Phaseolus* leaves.

7. Plant morphogenesis under weightlessness.

8. The role of gravitational stress in land-plant evolution: the gravitational factor in lignification.

Invertebrates (Bio F)

Scientific objectives.–To extend the survey and in-depth study of the responses of invertebrate animals to weightlessness, evolving from the results gained in the Biosatellite program toward plans for research in the Biotechnology Laboratory.

Justification.–

1. The biological scientific community has identified a need for these data arising from both survey and in-depth experimentation.

2. The manned space flight and bioscience communities have endorsed this activity as a means for evolving a flexible, responsive, and powerful mode of carrying out research on the above test subjects in the Biotechnology Laboratory.

3. The capability of long-term space systems to meet the environmental needs and the spacecraft support requirements must be evaluated in the operational environment (e.g., provision of a very low acceleration environment, and isolation of invertebrate-animal experiments from rhythmic or cyclic phenomena).

4. The ability of man to monitor, maintain, and repair experiments and equipment must be demonstrated operationally. The capability of the scientist/crewman must also be tested to determine whether he can:

a. Receive invertebrate animals, eggs, larvae, pupae, or other material.

b. Perform in-flight experimental preparation of animals for installation in onboard experiment modules.

c. Make direct observations of recordings on the test subjects.

d. Perform various specimen collection and preservation techniques, including biopsy, body-fluid sampling, sacrifice, and necropsy.

e. Make serendipitous or *ad hoc* demand observations.

f. Modify experiment protocol and conditions.

g. Terminate animal experiments, preparing both live specimens and preserved material for logistics return.

The requirement for, and role of, an invertebrate physiology/morphology specialist in a space station must be determined in operational tests.

5. Technological requirements must be satisfied for:

a. The evolution of invertebrate-animal research equipment for incorporation in the Biotechnology Laboratory.

b. Providing a low-g research environment free of rhythmic "cue" phenomena.

Component experiments.–

1. The effects of weightlessness, genetic diversity, and life cycle in *Drosophila melanogaster*.
2. Circadian rhythm–Vinegar gnat.
3. The circadian rhythm of the Madura roach in orbit.
4. Cockroach circadian rhythms during prolonged orbital flight.
5. The biorhythmicity of fiddler crab activity and respiration.
6. Discrimination and communication under weightless conditions.

Biotechnology Laboratory

Scientific objectives.–To provide a space-laboratory facility in which a broad spectrum of life-sciences experiments can be performed, making effective use of general-purpose or common equipment and the skills of scientist-astronauts. In particular, for space biology it will continue the investigations of organisms and phenomena indicated by prior survey experiments to be most worthy of intensive further work.

Justification.–

1. The biological community has identified a need for a substantial amount of space-flight research to gain a better fundamental knowledge of life processes, using exploration of the unique space environment as a research tool.
2. The presence of a life-scientist astronaut can greatly enhance the scientific value of biological experiments, substantially reduce the complexity of the equipment, and improve reliability.
3. The relative permanence, and the large volume and power capacity of the Biotechnology Laboratory, in conjunction with the astronaut, will permit the use of the equipment for repetition or variation of experiments without laborious development work. It should permit a lower cost per experiment and shorter time cycle for implementing experiments than are characteristic of the more highly automated facilities.

Future experiments.–Specific future experiments cannot be identified now with any useful accuracy, because they depend upon the results of preceding flights. However, it can be postulated that

the elements of the experiment complex will be adaptation of the earlier elements (i.e., Bio A–primates, Bio C–microbiology, Bio D–small vertebrates, Bio E–plants, and Bio F–invertebrates). Future efforts are expected to concentrate on such areas of study as:

1. Cellular life
2. Growth, aging, and longevity
3. Experimental embryology, differentiation, and regulation of morphogenesis
4. Genetics
5. Plant studies–geotropism
6. Basic microbiology and immunology
7. Animal behavior
8. Biorhythms–circadian and others
9. Radiation effects in space
10. Mammalian physiology and adaptation, including the following systems–
    a. Cardiovascular
    b. Renal and urinary
    c. Neurophysiological
    d. Musculoskeletal
    e. Metabolic
    f. Respiratory
    g. Endocrine

Experiment Requirements and Constraints

The bioscience research program requires the lowest possible acceleration environment for the proper conduct of experiments to investigate the effect of weightlessness on life forms. This requirement stems from the lack of baseline knowledge of the g-sensitivity thresholds for biological systems, from cellular and subcellular levels to total organisms. Initial estimates indicate that the maximum nominal g-environment should be no greater than 10^{-4} g for 90 percent of the time. An acceleration environment of 10^{-3} can be accommodated for 10 percent of the time, integrated over the duration of the mission. Pulses up to 1 g can be accepted occasionally, if the pulse duration is less than 1 minute. All pulses above the nominal environment of 10^{-4} g should be predictable, and sufficient advance notice be given to the experimenter to

permit him to protect all experiments against the adverse effects of the acceleration pulse. Exact records of the g-levels, weight of onset, and duration must be provided the experimenter to permit him to identify experimental anomalies resulting from the g-pulse.

To permit meaningful research in biorhythms, all pertinent bioscience experiments must be isolated from any 24-hour periodic cues or harmonics thereof which result from acceleration, noise, lighting, thermal changes, crew activity, etc.

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